Three-Dimensional Virtual Endoscopy for Laparoscopic and Thoracoscopic Liver Resection

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During the last 2 decades, computer-aided diagnosis and intervention planning has garnered increasing interest. Recently, virtual navigation systems have been applied to hepatic surgery, enabling excellent visualization of the intrahepatic vascular branches and precise localization of tumors.[1-4] Although these systems are being used by several surgeons in clinical settings, there are few reports on the use of detailed intraoperative virtual imaging systems for laparoscopic surgery based on the laparoscopic perspective.[5] Anatomical information in laparoscopic liver surgery represents a unique circumstance because the laparoscope is restricted by the positions of the trocars, the abdominal cavity, and the resection area of the liver, which collectively contribute to a poorer laparoscopic visual field than that for open liver surgery.[6] Here we report on a laparoscopic liver resection protocol using a 3-dimensional (3D) virtual navigation system. Using these procedures, the surgeon can perform safe and accurate laparoscopic liver surgery under realistic anatomic conditions.

METHODS

Patients

From April 2010 to March 2014, one hundred and six patients underwent laparoscopic or thoracoscopic liver resection for hepatic malignancy at Showa University. Among these patients, the first 12 who underwent laparoscopic or thoracoscopic liver resection under the direction of a 3D virtual navigation system are presented in this study. The median age of these 12 patients was 61 years (range 51 to 80 years). The male-to-female ratio was 7:5. The pathologic diagnoses of the lesions were hepatocellular carcinomas in 6 patients and colorectal liver metastases in 6 patients. Patient characteristics are listed in Table 1.

Preoperative resection planning under virtual laparoscopy

All patients underwent preoperative CT to display the arterial, portal venous, and hepatic venous anatomy. The preoperative CT imaging protocol, performed with a 64-row multidetector CT scanner (Somatom Definition AS; Siemens), obtained image sets after IV injection of a nonionic contrast agent (Iomeron, 630 mgI/kg; Eisai) at a rate of 4 mL/s with the following parameters: 100 kV; 400 mAs; section thickness, 0.75 mm; and collimation, 0.7 mm. Better visualization of anatomical structures required IV contrast enhancement. These images were then uploaded to Synapse Vincent image processing software (Fujifilm Medical).

Surgical planning was performed by the surgeons using Synapse Vincent software. This tool enables the surgeon to review reconstructed liver structures (ie, liver parenchyma, portal veins, hepatic veins, and tumor tissue), perform virtual hepatectomy (eg, segmentation results and definition of a resection plane), and generate virtual endoscopic 3D geometries that accurately represent the cartography of the liver. Surgeons can confirm both the liver anatomy and spatial relationship between vessels and tumors to ensure a safe liver resection. In Japan, operative evaluations using image processing software for liver surgery have been covered by universal health care insurance since 2012. Each case is charged approximately $200 for the volumetric evaluation.[7]

Intraoperative assistance by 3-dimensional virtual endoscopy

For orientation and guidance during the operation, the navigation image was displayed on an additional monitor, onto which virtual 3D imaging was transferred from an iPad (Apple). The surgeon could refer to the orientation and check the anatomy on the monitor compared with the actual intraoperative view. For each case, the surgeons were briefly interviewed to obtain feedback on the use and usability aspects of the 3D imaging because it is related to the surgical case.

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Table 1. Patient Characteristics and Pathologic Variables of Patients Who Underwent Laparoscopic or Thoracoscopic Liver Resection for Hepatic Malignancy at Showa University

Variable	
Age, y, median (range)	61 (51–80)
Male/female, n	7/5
Background liver status, n	
Normal/chronic hepatitis/cirrhosis	6/3/3
Histology, n	
Hepatocellular carcinoma	6
Metastatic liver tumor	6
Tumors, n, median (range)	1.1 (1–2)
Size of largest tumor, mm, median (range)	22.3 (15–35)

RESULTS

Mean operative time was 95 minutes (range 55 to 145 minutes), with a mean blood loss of 44 g (range 0 to 155 g). No cases required intraoperative transfusion. Mean surgical margin was 8 mm. No cases required conversion to open surgery and there were no instances of postoperative morbidity or mortality (Table 2).

Case presentation

Patient 1

A 65-year-old man was admitted to our hospital to undergo video-assisted thoracoscopic surgery hepatectomy for hepatocellular carcinoma.[8] The tumor was 3 cm in diameter and was located in Couinaud's segment VIII. Optimal placement of ports, enhanced visualization of vessels supplying the tumor, and anatomic landmarks were simulated before surgery using 3-dimensional virtual endoscopy (3DVE) (Fig. 1). Partial liver resection was scheduled. Video-assisted thoracoscopic surgery hepatectomy was performed via 1 port, and 2 laparoscopic protectors were placed in the fifth intercostal space according to the simulation on 3DVE. The tumor location was confirmed by the 3DVE image, and the portion of the diaphragm located just above the tumor was then incised to expose the liver surface under intraoperative thoracoscopic ultrasonography. When the liver parenchyma was progressively transected, the positioning of the vessels and tumor that should be exposed and resected was confirmed by the surgeon from a variety of angles based on the laparoscopic approach with this simulation (Fig. 2 and Supplementary Video 1). This system helped the surgeon to achieve early bleeding control and maintain a visually bloodless procedure. The total operative time under the 3DVE guidance was 105 minutes. The procedure did not require conversion to open surgery or perioperative transfusion. The patient's postoperative course was uncomplicated and he was discharged 7 days after the operation.

Table 2. Type of Resection and Surgical Outcomes for Patients Who Underwent Laparoscopic or Thoracoscopic Liver Resection for Hepatic Malignancy at Showa University

Variable	
Technique, n	
VATS hepatectomy	5
Laparoscopic hepatectomy	7
Extent of resection, n	
Wedge	6
Segmentectomy	6
Total operative time, min	
Range	55–145
Median	95
Estimated blood loss, g	
Range	0–155
Median	44
Tumor exposure, n	
Yes	0
No	12
Median tumor margin, mm	8
Morbidity, %	0

Patient 2

A 64-year-old man was diagnosed with hepatocellular carcinoma and admitted to our hospital for laparoscopic liver resection. The tumor, measuring 4.5 cm in diameter and located in Couinaud's segment III, was detected on background hepatitis C chronic liver disease (Child-Pugh class A). The patient was placed in the supine position with both hands extending laterally. A 5-trocar configuration was used based on the guidance from 3DVE.

Intrahepatic vascular structures were identified from 3DVE based on landmarks present on the outer surface of the liver. These landmarks enabled identification of the segment margins and offered a useful guide to performing left lateral segmental hepatectomy. Using the 3DVE system, the corresponding left lateral sectional branches of the hepatic artery were then identified easily under the instruction of 3DVE in the running course from the umbilical/posterior point. After thorough identification, these branches were controlled and divided within the liver parenchyma. In addition, we identified and confirmed the segmental portal branch segments 2 and 3, and transected them by gentle tactile transection on the leaflets of the capsule using dissection forceps. From this point, the bifurcation sites of portal branches P2 and P3 were clearly identified and were individually dissected, clipped, and ligated (Fig. 3 and Supplementary Video 2). This procedure provided an easy, reliable approach to identifying the individual branches, which were enclosed by a sheath of connective tissue to the left of the umbilical fissure.

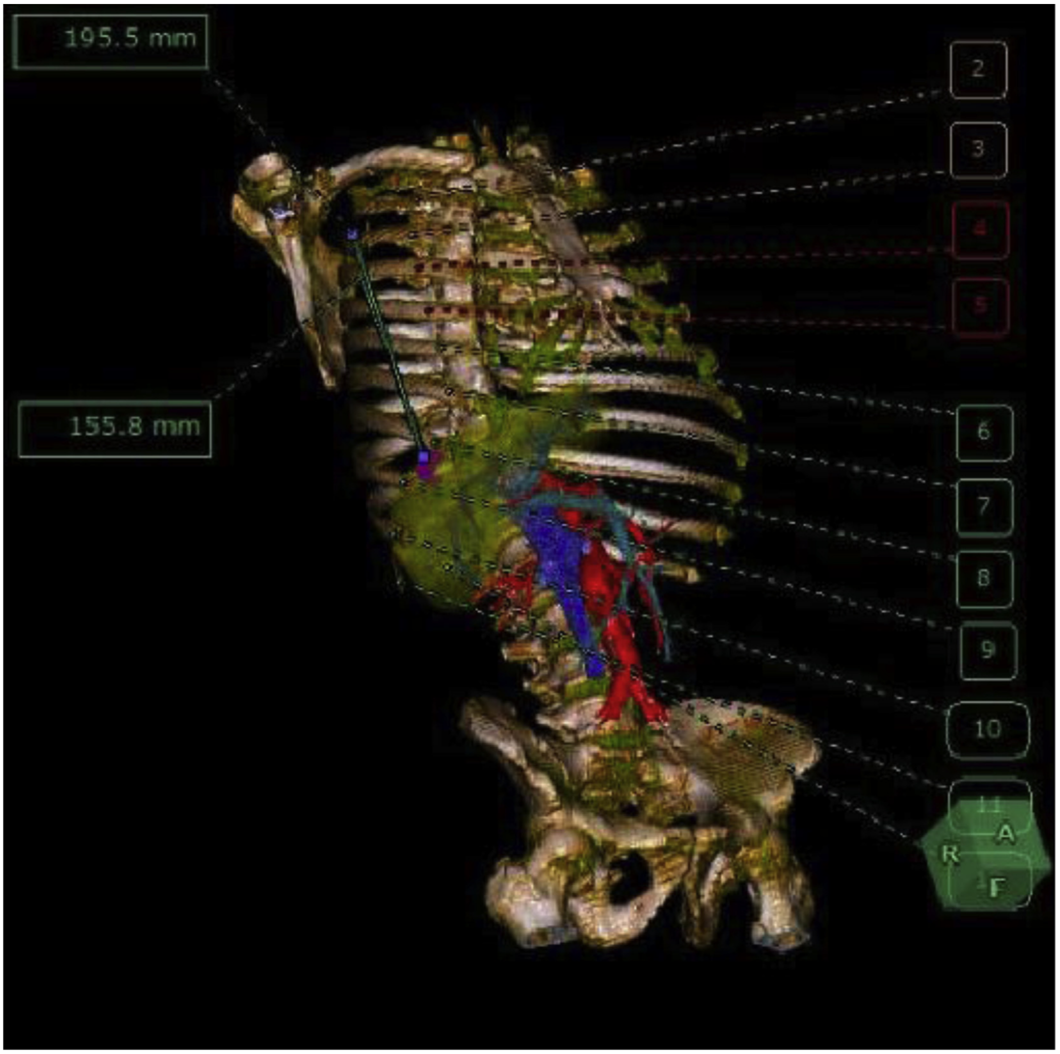

Figure 1. Preoperative simulation of port position using 3-dimentional virtual endoscopy (3DVE). Optimal placement of ports position were simulated prior to surgery using 3DVE.

Use of 3DVE enabled early bleeding control and a virtually bloodless procedure. Finally, we used a laparoscopic linear stapler device for division of the hepatic vein branches and to complete parenchymal transection. The total operative time under 3DVE guidance was 90 minutes. The procedure did not require conversion to open surgery or perioperative transfusion. The patient's postoperative course was uneventful and he was discharged 7 days after the operation.

DISCUSSION

Our experience suggests that the novel intraoperative 3DVE reference image used in this study enabled efficient and accurate intraoperative identification of the vascular tree (ie, hepatic and portal veins) and localization of the tumor. This technique can also be useful for determining preoperative port tuning; it helps to avoid potential interference between forceps and allows the surgeon to both preoperatively plan the resection and read the resection mapping.

It seems that the major advantage of this system was its ability to accurately depict improved intraoperative anatomical orientation based on a laparoscopic perspective. This feature makes it easier for surgeons to understand the exact tumor location in relation to surrounding vessels than with conventional imaging systems, such as CT and MRI, which provide visualization but without a laparoscopic viewpoint; this is because preoperative visualization of CT/MRI imaging must be "reconstructed in a 3D context" in the surgeon's "mind eye" to guide orientation of the liver structures

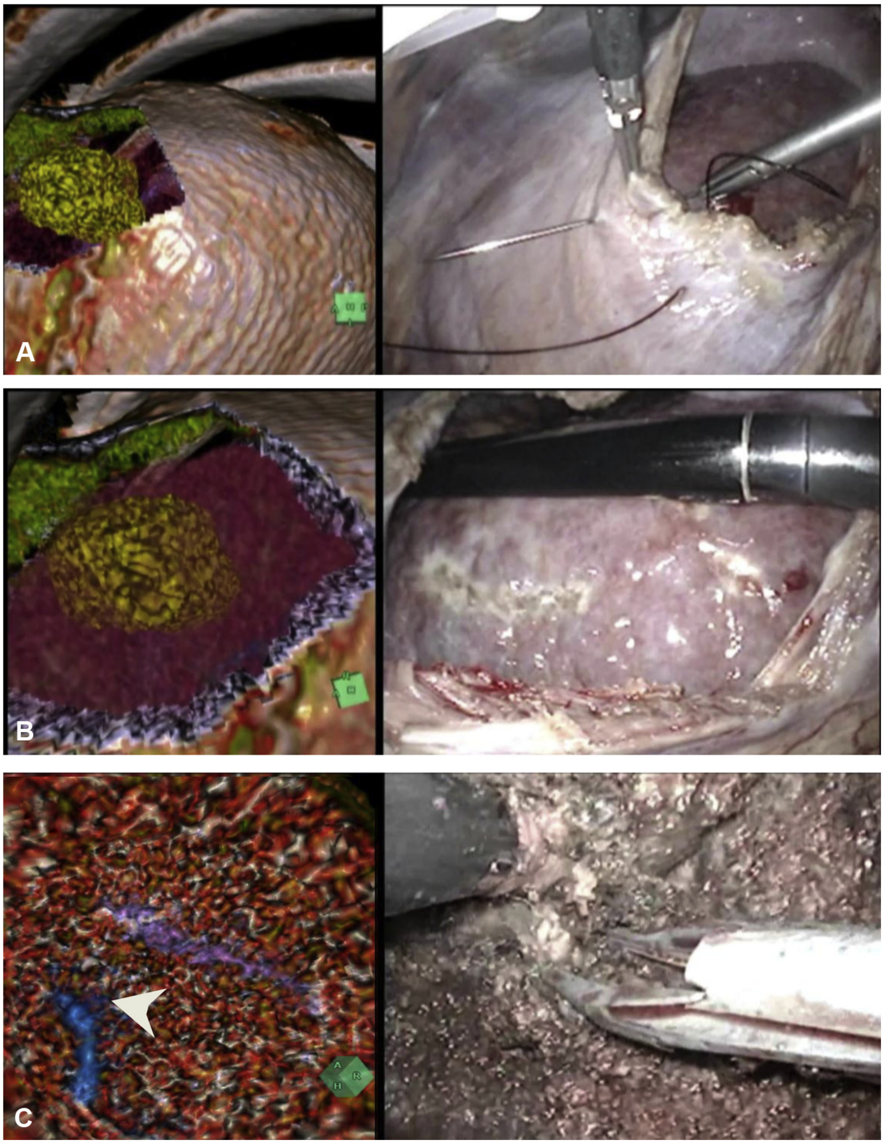

Figure 2. Each row shows the 3-dimensional virtual endoscopy (3DVE) image (left column) and the original laparoscopic camera image (right column). (A) The tumor location was confirmed on the 3DVE, and then the portion of the diaphragm located just above the tumor was opened. (B) Intraoperative thoracoscopic ultrasonography was performed on the liver surface to identify the tumor margin. (C) Clips were applied on segmental branch 8 of the portal vein before dissection (arrow). See Supplementary Video 1.

and tumors.[9] In this case series, simultaneous visualization of 3DVE was useful for confirming the location of the tumor and hepatic vessel branches in the transection plane of the liver (patient 1) and for determining the most appropriate site for division of the Glissonean pedicle (patient 2). Another advantage of this system was that ports can be localized to avoid interference between the forceps and laparoscope; this provides the surgeon with a larger working space. Previously, surgeons have had to imagine spatial relationships between structures based on 2-dimensional information from CT or ultrasound.[6] However, using this system can provide clear and accurate visualization of the specific anatomic conditions through creation of objective 3D images based on a laparoscopic perspective. In this manner, surgeons can share and discuss reproducible anatomic information without bias stemming from their relative experience or expertise.

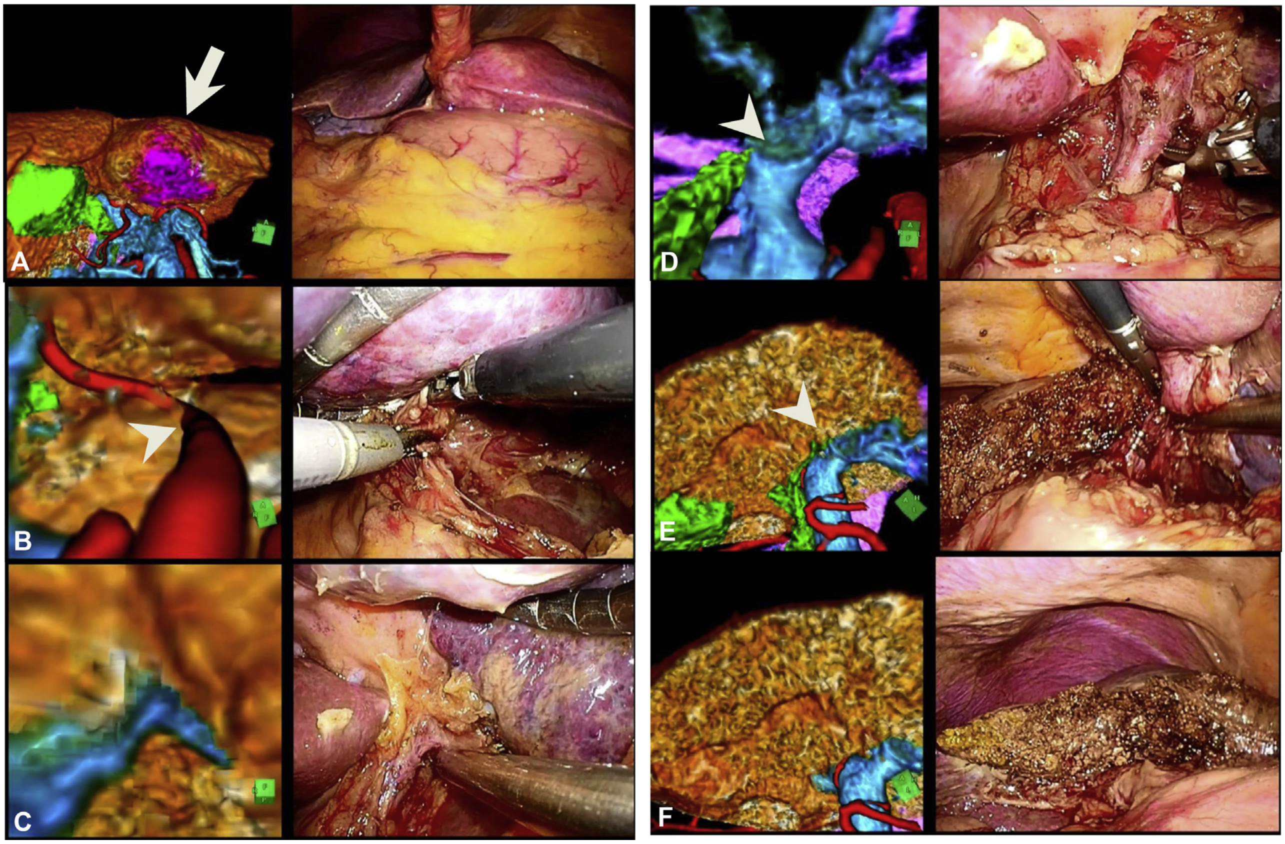

Figure 3. Each row shows the 3-dimensional virtual endoscopy (3DVE) image (left column) and the original laparoscopic camera image (right column). (A) The tumor (arrow) was located in Couinaud's segment III. (B) Clips were applied on the lateral sectional branch of the hepatic artery (arrowhead) before dissection. (C) Identification of the left portal branch. (D) Clips were applied on portal segmental branch 2 (P2) (arrowhead). (E) Clips were applied on portal segmental branch 3 (P3) (arrowhead) before dissection. (F) The sectional branch of the left hepatic vein was transected using a laparoscopic linear stapler. See Supplementary Video 2.

A potential drawback of the present imaging system is that data for 3DVE cannot be directly transferred to intraoperative situations because of organ shifting and deformation of the liver or respiratory moments during resection. Structure visualization must allow a margin of error for slight variation. Solutions for precisely aligning preoperative imaging data and intraoperative simulation remain to be established. Although the most frequently used intraoperative imaging technique is ultrasound, because of its widespread availability and continuous improvement in its diagnostic qualities,[10,11] this modality is limited by the fact that it must be used in the abdominal cavity through the trocar.[12] In addition, imagining and interpreting structures in the resection plane is difficult once resection has started. There is an ongoing need to efficiently enhance the safety of surgical procedures by providing the surgeon with an accurate localization of critical structures during liver resection.[7]

Use of virtual navigation systems in hepatobiliary procedures was only started within the last few years.[2-5,7] These systems are expected to complement conventional imaging modalities, such as ultrasound, CT, and MRI. To address the clinical need for intraoperative navigation for safer laparoscopic liver resection, our approach is to present the surgeon with 3DVE from a laparoscopic perspective. This concept requires the surgeon to simulate the operating map before surgery from the viewpoint of the laparoscope, and it facilitates the safe performance of surgical procedures with identification of hepatic structures and the tumor location using this system in the laparoscopic field. In the near future, it would be ideal to conduct a randomized controlled study to comparing the operative outcomes and costs associated with the use, and without the use, of 3DVE.

CONCLUSIONS

Our early experience suggests that 3D virtual navigation with a "laparoscopic eye" efficiently displays intraoperative 3D data and contributes to safer and more accurate hepatic surgery, although additional improvements are needed to establish a "true" navigation system.

Author Contributions

Study conception and design: Aoki, Murakami
Acquisition of data: Koizumi, Fujimori, Gareer, Enami, Koike, Watanabe, Otsuka
Analysis and interpretation of data: Aoki, Enami
Drafting of manuscript: Aoki, Murakami
Critical revision: Aoki, Murakami

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